REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
8/16/2012

2. REPORT TYPE
Final

3. DATES COVERED *(From - To)*
May 2009-May 2012

4. TITLE AND SUBTITLE
First Light Infrared Observations with the 1.6 Meter Solar Telescope in Big Bear: Origins of Space Weather Telescope.

5a. CONTRACT NUMBER
FA9550-09-1-0655

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Philip Goode, PI

5d. PROJECT NUMBER
AFOSR-BAA-2008-1

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
New Jersey Institute of Technology
University Heights
Newark, NJ, 07102

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Office of Scientific Research
Air Forcee Defense Research Sciences Program

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFRL-OSR-VA-TR-2012-1098

12. DISTRIBUTION AVAILABILITY STATEMENT

13. SUPPLEMENTARY NOTES
DISTRIBUTION A: APPROVED FOR PUBLIC RELEASE

14. ABSTRACT
In early 2009 at Big Bear Solar Observatory (BBSO), first light science observations were made with BBSO's New Solar Telescope (NST), which is a 1.6 m clear aperture, off-axis telescope. The NST is the first facility-class solar telescope built in the U.S. in a generation. Earlier AFOSR support was critical in bringing the telescope to fruition, as well AFOSR funding paid for much of the post-focus hardware for measuring magnetic fields. Such measurements are critical in our efforts to probe the origin of space weather events.

We investigated properties of magnetic fields in nearly 400 solar active regions. Time profiles of magnetic helicity injection rate, magnetic helicity accumulation, and unsigned magnetic flux were analyzed. Our objective was to examine the feasibility of using these quantities for flare forecasting. Previous studies by a number of other authors already demonstrated correlation between the total unsigned magnetic flux in an active region and the flare productivity. We intended to find if magnetic helicity injection will carry extra weight in predicting flares. In detail, we calculated the four magnetic parameters (absolute average magnetic helicity injection rate, peak unsigned magnetic helicity injection rate, peak unsigned magnetic helicity accumulation, and average unsigned magnetic flux) during a period of 24 hours after an active region appears or rotates to a position within 0.6 of the solar radius from the apparent disk center. We then compare these parameters with the flare index derived from GOES soft X-ray observation for the time window of 24 hours, after the magnetic parameters measurement. Correlation between the magnetic parameters and the flare index provides a tool to predict future events.

INSTRUCTIONS FOR COMPLETING SF 298

15. SUBJECT TERMS Space Weather					
16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT** UU	**18. NUMBER OF PAGES** 2	**19a. NAME OF RESPONSIBLE PERSON** Norma Rubio
a. REPORT U	**b. ABSTRACT** U	**c. THIS PAGE** U			**19b. TELEPONE NUMBER (*Include area code)*** U973-596-5275

Final Report (5/1/09-4/30/12)

AFOSR Grant, FA9550-09-1-0655

First Light Infrared Observations with the 1.6 Meter Solar Telescope in Big Bear: Origins of Space Weather Telescope.

PI: Philip R.Goode, New Jersey Institute of Technology

In early 2009 at Big Bear Solar Observatory (BBSO), first light science observations were made with BBSO's New Solar Telescope (NST), which is a 1.6 m clear aperture, off-axis telescope. The NST is the first facility-class solar telescope built in the U.S. in a generation. Earlier AFOSR support was critical in bringing the telescope to fruition, as well AFOSR funding paid for much of the post-focus hardware for measuring magnetic fields. Such mueasurements are critical in our efforts to probe the origin of space weather events.

Early in the summer observing season of 2010, light was brought to the Coude Lab on the floor beneath the telescope. There the new telescope feeds its light to its operational 97 actuator DM based AO system, which in turn feeds Halpha, white light, G-band, TiO and the infrared imaging magnetograph (IRIM). Halpha is for chromospheric studies, while G-band and TiO are for the study of small scale photospheric features. IRIM is a Fabry-Perot based system for measuring the magnetic field in near infrared (IR), as well as the Fast Imaging Solar Spectrograph (FISS). FISS is a dual channel spectrograph for scanning two spectral lines for altitude resolution.

The NST offers an essential and significant improvement in ground-based high angular resolution capabilities that has already substantially enhanced our continuing program to understand photospheric magneto-convection and chromospheric dynamics. These are the drivers for what is broadly called space weather – an important problem, which impacts human technologies and life on Earth. The NST project is described in detail www.bbso.njit.edu/newtelescope.

The NST has an off-axis Gregorian configuration consisting of a parabolic primary, heat-stop, elliptical secondary and diagonal flats. The focal ratio of the primary mirror is f/2.4, and the final ratio is f/50. The working wavelength range covers from 0.39 to 1.7 microns in the Coude Lab beneath the telescope and all wavelengths including the far infrared at the Nasmyth focus on the dome floor. We emphasize that both the NST and ATST are off-axis designs. We have made scientific observations in TiO and Halpha

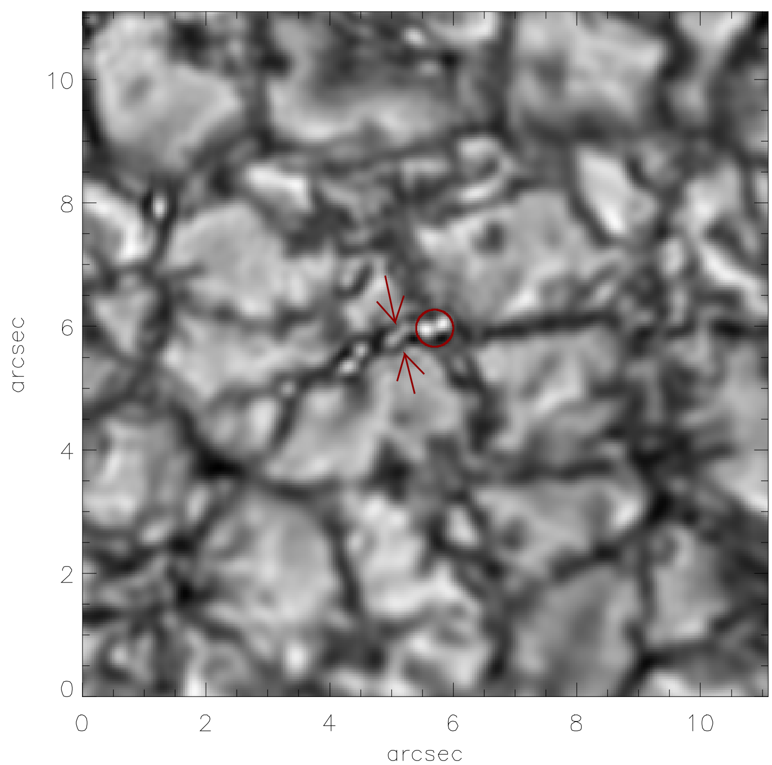
This grant has supported two postdoctoral staff in BBSO. Most recently, Dr. Eun-Kyung Lim was supported, and she was preceded by Dr. Jongchul Chae.

Six Science Projects Performed under FA9550-09-1-0655

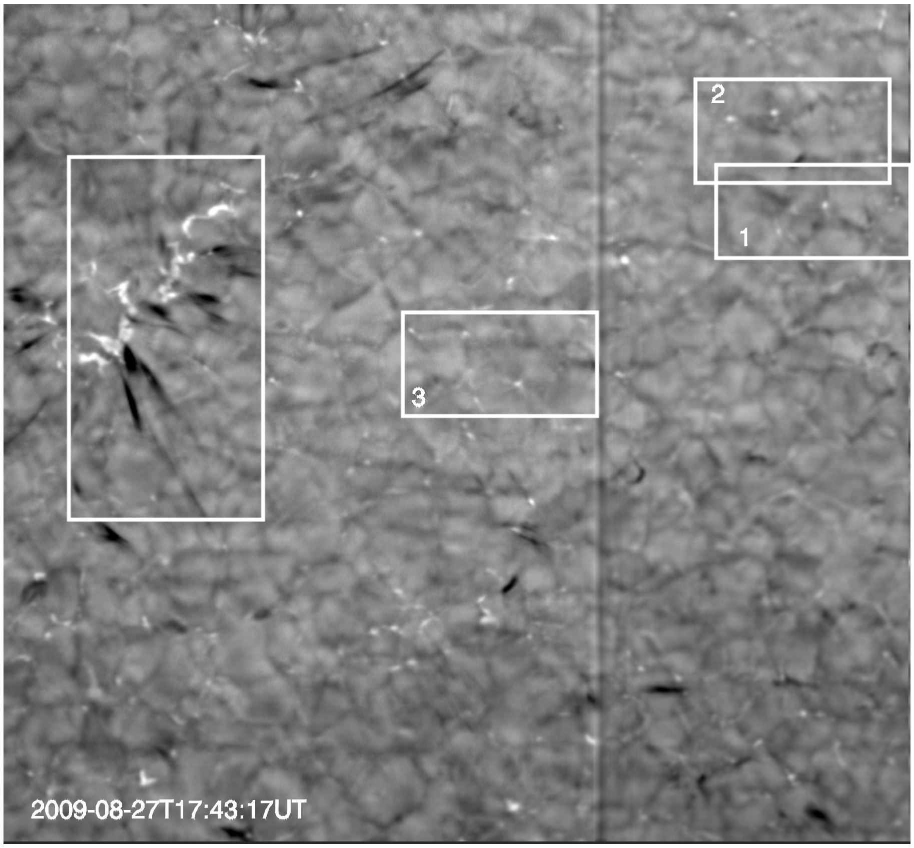
1)Our studies have demonstrated without doubt that the magnetic field in the photosphere and corona is an intermittent structure, opening new views of the underlying physics. In particular, such problems as the existence in the corona of localized areas with extremely strong resistivity (required to explain magnetic reconnection at all scales) and the interchange between small and large scales (required in the study of photospheric-coronal coupling), to name a few, can be easily captured by the concept of intermittency. This study focuses on simultaneous time variations of intermittency properties derived in the photosphere, chromosphere, and corona. We analyzed data for NOAA Active Region 10930 acquired between 2006 December 8, 12:00 UT, and December 13, 18:45 UT. Photospheric intermittency is inferred from Hinode magnetic field measurements, while intermittency in the transition region and corona is derived from Nobeyama 9 GHz radio polarization measurements and high-cadence Hinode XRT (thin-Be) data, as well as GOES 1-8 Å flux. The photospheric dynamics and its possible relationship with the intermittency variations are also analyzed by calculating the kinetic vorticity. In this case study, we find the following chain of events: The intermittency of the photospheric magnetic field peaked after the specific kinetic vorticity of plasma flows in the active region reached its maximum (4 hr time delay). In turn, a gradual increase of coronal intermittency occurred after the peak of the photospheric intermittency. The time delay between the peak of photospheric intermittency and the occurrence of the first strong (X3.4) flare was approximately 1.3 days. Our analysis seems to suggest that the enhancement of intermittency/complexity first occurs in the photosphere and is later transported toward the corona.

2)We investigated properties of magnetic fields in nearly 400 solar active regions. Time profiles of magnetic helicity injection rate, magnetic helicity accumulation, and unsigned magnetic flux were analyzed. Our objective was to examine the feasibility of using these quantities for flare forecasting. Previous studies by a number of other authors already demonstrated correlation between the total unsigned magnetic flux in an active region and the flare productivity. We intended to find if magnetic helicity injection will carry extra weight in predicting flares. In detail, we calculated the four magnetic parameters (absolute average magnetic helicity injection rate, peak unsigned magnetic helicity injection rate, peak unsigned magnetic helicity accumulation, and average unsigned magnetic flux) during a period of 24 hours after an active region appears or rotates to a position within 0.6 of the solar radius from the apparent disk center. We then compare these parameters with the flare index derived from GOES soft X-ray observation for the time window of 24 hours, after the magnetic parameters measurement. Correlation between the magnetic parameters and the flare index provides a tool to predict future events.

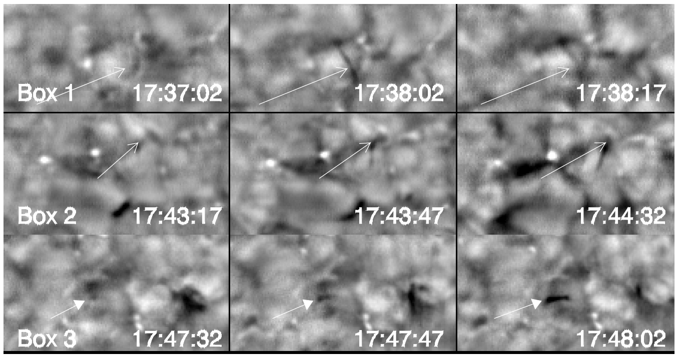
3)In the figure below, we show the typical granular subfield observed in TiO (706 nm) with a field of view of 12"x12" (5000x5000miles). The nearly circular bright points in the dark lanes are horizontal cross sections of nearly vertical fibers of the intergranular magnetic field shown in intensity. The bright points were observed to be separated, rather than continuous. Future observations with the NST should reveal the structure of the points. The red arrows indicate two bright points that are destroyed when the granules collide, and the two indicated by the right-side circle indicate two bright points that are sent whirling about each other after the destructive collision.



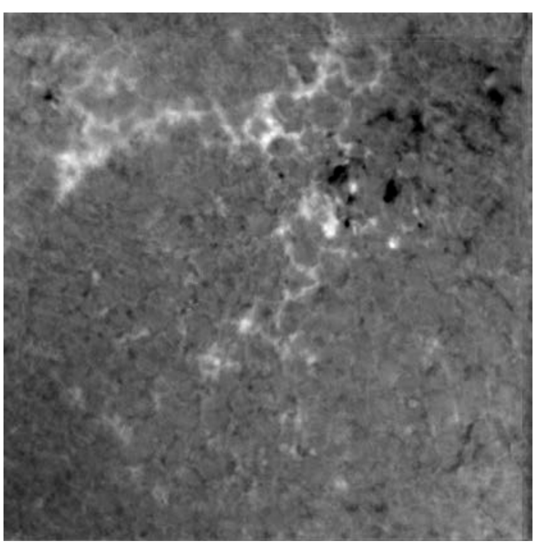
4)NST off-band Halpha (-0.13nm off-band, corresponding to a Doppler blue shift of about 60km/s) image acquired on August 27, 2009. The three small white boxes indicate regions of interest shown in detail in the figure below. These regions show intriguing small-scale elongated, dark features bisecting a granule (Box 1), originating in a dark lane (Box 2), and inclined to reveal a loop-like structure (Box 3). Each small box indicates the behavior of new features discovered with the NST. As for the large white box, we note that the large dark and elongated structures therein may be identified as rapid upflow events and are thought to be disk counterparts of type II spicules.

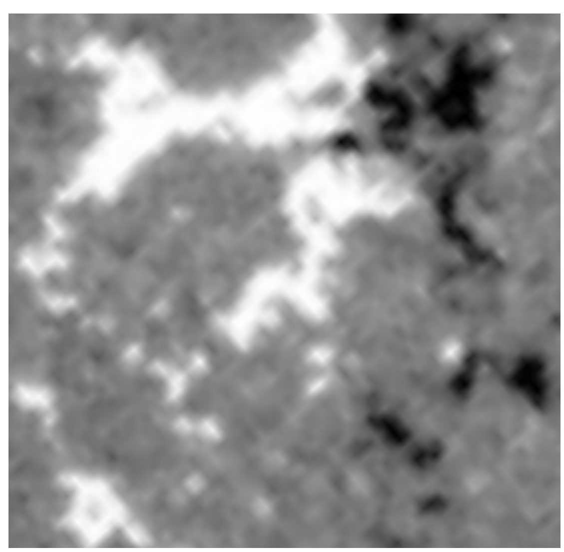


Time evolution of the newly discovered events that occurred in each of the smaller boxes in the figure above are shown in the figure below. Each row of images represents the evolution of a single event. The top row shows an event that arcs over a granule seeming to bisect it. The middle row shows an event emerging from a dark lane. The bottom row shows an event with a clear arc structure. The first row shows an event that persisted for at least 30s, and it neatly bisects the underlying granule. The second row shows another event originating in a dark lane and traversing the granule. Even though these tiny events are ubiquitous, it was not easy to find one clearly revealing their common origin in the dark lanes because most of them suddenly appear as a streak across a granule. During a 15s timestep, these events would show a streak over about 700-900km so that the time cadence of 15s is not typically sufficient to resolve their development. One can see, therefore, that to observe these tiniest of events, we should have a cadence of about 5s or better, which will come soon for the NST. The third event lasted somewhat longer and can be seen extending and curving, as if it were plasma moving along a field line belonging to a loop.

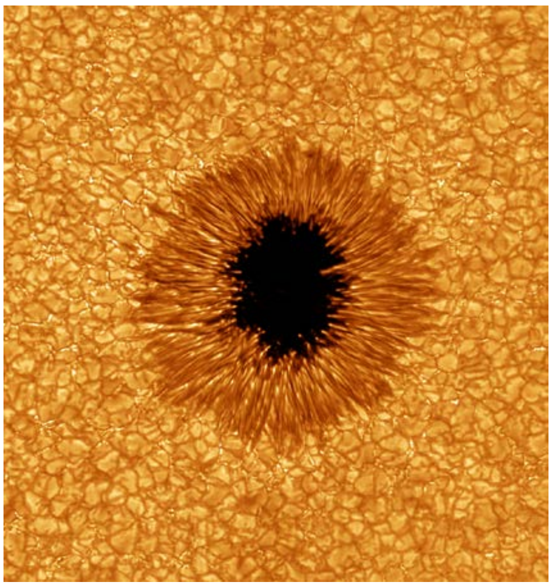


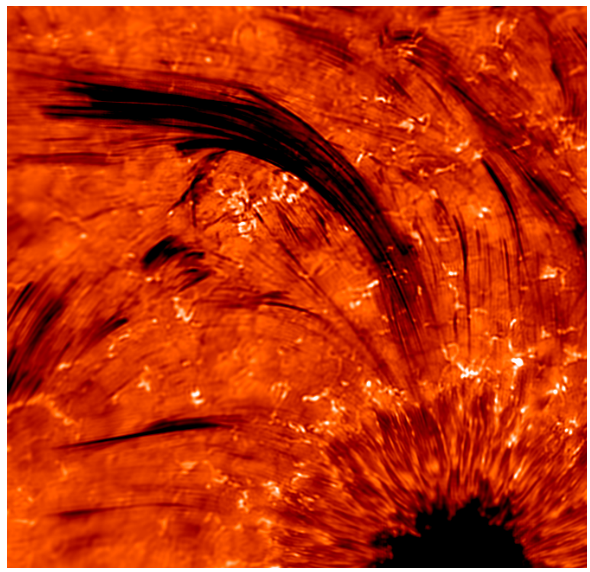
5)We do not know what these events are that we discovered with the NST. It has yet to be established whether these intergranular events are pure upflows (jets), and how their dynamics might be associated with the underlying dynamics of convective flows and turbulent magnetic fields. An extensive analysis of solar data, which would rely on magnetic field data, needs to be carried out with high spatial, temporal and spectral resolution. Two interpretations are offered, although their origin remains open. First, they may represent smallest scale jets accelerated by a reconnection between the intergranular ambient magnetic fields and the turbulent fields churned up by granular flows. Alternative possibilities are that they may be either a result of oscillations and turbulent photospheric flows leaking into the lower chromosphere or shearing motions of photospheric footpoints of vertical magnetic field lines. We have begun to make vector magnetic field observations with IRIM to determine their origin and relation to space weather, but the key has been simultaneous observations of the local magnetic field. This has been achieved and is illustrated in the figure below for the quiet Sun. It is compared side by side with a magnetogram from the latest NASA satellite, the Solar Dynamics Observatory (SDO), which is so much in the news of late. The two magnetograms are from the same place on the Sun, but 10 minutes apart. The NST magnetogram (on the left) is much sharper showing many small scale features with the SDO magnetogram (on the right) showing the same but blurrier features.





6)In the summer of 2010, the NST was outfitted with adaptive optics, which resulted in a major improvement in image quality. The AO system resides in the Coude Lab beneath the telescope floor. Below we show images of a sunspot taken in 2010. We have made scientific observations in TiO and Halpha and two are shown immediately below. The sunspot on the left was chosen by the editors of National Geographic as one of the top ten space images of 2010. The image of the same spot in Halpha (off-band) shows jets (dark fibers coming from the edge of the penumbra). The narrowest fibers are about 0".1, which is close to the diffraction limit of the NST at that wavelength.





Publications in Refereed Journals under FA9550-09-1-0655

Highest Resolution Observations of the Quietest Sun, 2010, P. R. Goode, V. Yurchyshyn, W. Cao, V. Abremenko, A. Andic, K. Ahn, J. Chae, ApJLett, 714, L31.

Oscillatory Behavior in the Quiet Sun Observed with the NST, 2010, A. Andic, P.R. Goode, J. Chae, W. Cao, K. Ahn, V. Yurchyshyn, V. Abramenko, ApJLett, 717, L79-L82.

New Solar Telescope Observations of Magnetic Reconnection Occurring in the Chromosphere of the Quiet Sun, 2010, J. Chae, P. R. Goode, K. Ahn, V. Yurchyshyn, V. Abramenko, A. Andic, W. Cao, Y. D. Park, ApJLett, 713, L6.

The NST – First Results and Some Lessons for ATST and EST, 2010, P.R. Goode, R. Coulter, N. Gorceix, V. Yurchyshyn, W. Cao, Astron. Nachr., 331, No. 6, 620, doi 10.1002/asna.201011387

Response of Granulation to Small-Scale Bright Features in the Quiet Sun, 2011, A.Anđić, J. Chae, P. R. Goode, W. Cao, K. Ahn, V. Yurchyshyn and V. Abramenko, ApJ, 731, 29

The New Solar Telescope in Big Bear: Polarimetry I, 2011, P. R. Goode, W.
On the Origin of Intergranular Jets, 2011, V. B. Yurchyshyn, P.R. Goode, V.I. Abramenko, O. Steiner, ApJLett, 736, 35L

Photospheric Signatures of Granular-scale Flux Emergence and Cancellation at the Penumbral Boundary, 2011, E.-K. Lim, V. Yurchyshyn, V. Abramenko, Valentyna; K. Ahn, W. Cao, P.R. Goode, ApJ, 740, 82

New Solar Telescope in Big Bear: Evidence for Super-Diffusivity and Small-Scale Solar Dynamos, P.R. Goode, V. Abramenko, V. Yurchyshyn, 2012, Phys. Scr., 86, 018402